

## Estimating the Potential for Facilitated Transport of Napropamide by Dissolved Organic Matter

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### ABSTRACT

Dissolved organic matter (DOM) has been found to significantly affect the soil sorption/desorption of napropamide [2-( $\alpha$ -naphthoxy-N, N-diethylpropionamide)] and to enhance its transport through soil columns. A method to qualitatively predict if DOM will enhance the transport of napropamide based on easily determined sorptive characteristics is investigated. Batch sorption experiments were specifically designed to simulate field application of napropamide. The formation of a napropamide-DOM complex was enhanced by pretreating soils with pesticide and allowing the carrier solvent to evaporate prior to preparing a water extract of the soil (K1). A second adsorption coefficient was measured by equilibrating K1 with untreated soil (K2). Column transport studies using the same soils as the batch equilibrium studies were performed. After allowing napropamide to dry, columns were leached. Initial leachate from all soils contained napropamide indicating that the collected napropamide had been transported through the column without adsorption. However, the amount leached was dependant on soil type and in general soils with higher organic matter content had higher concentrations of napropamide in the initial 30 mL of leachate when compared with lower organic matter (OM) soils. The ratio of the K1 and K2 solutions from the batch equilibrium studies were found to be positively correlated with the mass of napropamide in the initial leachate. Therefore the ratio of K1 to K2 provided a better qualitative predictor of the potential for facilitated transport of napropamide than soil OM content.

**M**OST AGRICULTURALLY APPLIED pesticides are slightly soluble organic compounds that potentially degrade the environment. They can be transported by runoff from treated fields and appear in surface water bodies or they may be carried by water flowing through the soil profile and degrade ground waters. The focus of this paper will be on the potential for ground water degradation by surface applied napropamide, and the development of a qualitative predictor for the facilitated transport of this pesticide by DOM.

The transport of pesticides through soil by flowing water is retarded by adsorption to the soil. The retardation factor ( $R$ ), defined as the ratio of the rate of pesticide transport to the rate of water flow, is related to the adsorption coefficient by the equation

$$R = 1 + \rho_b K_d / \theta_v \quad [1]$$

where  $K_d$  is the adsorption coefficient,  $\rho_b$  is the soil bulk density, and  $\theta_v$  is the volumetric soil water content.

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Some researchers have shown that small fractions of applied pesticides are transported deeper into the profile than would be expected based on the measured retardation coefficient. Examples of such reports include Jury et al. (1986), Shipitalo et al. (1990), Kladvko et al. (1991), Ghodrati and Jury (1992), and Grochulska and Kladvko (1994). These results were attributed to preferential flow where the pesticide-laden water was transported through large pores or zones where the water flow was very rapid when compared with the average water flow rate through the soil, thus minimizing solute contact with soil surfaces.

Other mechanisms, in addition to preferential flow, can contribute to the rapid transport of pesticides through soil. Colloid enhanced transport could occur by adsorption of the pesticide to particulates that are carried by the flowing water. Vinten et al. (1983) found that paraquat (1,1'-dimethyl-4,4'-bipyridinium) and DDT [1,1'-(2,2,2-Trichloroethylidene)bis(4-chlorobenzene)] were much more mobile in soil when bound to Li-montmorillonite colloids. Water dispersible colloids were observed to increase the transport of atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine] through intact soil columns by Seta and Karathanasis (1997a, 1997b).

Dissolved OM can also enhance transport when the pesticide is bound to or complexed with the DOM. Ballard (1971) found that soil derived humic substances formed a complex with DDT and increased its mobility through the organic layers of forest soils. Graber et al. (1995) found that irrigation with secondary treated sewage effluent lead to enhanced transport of atrazine in field soils when compared with irrigation with regular water. The enhanced transport of atrazine was attributed to the association of atrazine with organic constituents in the sewage effluent. The enhanced transport of herbicides through soil columns with solutions containing dissolved organic C was observed by Baskaran et al. (1995). Water-soluble organic materials were found to be capable of binding to several herbicides and it was postulated that the resulting complex would be more mobile than would be predicted based on the standard  $K_d$  measurement (Madhun et al., 1986). Kogel-Knaber et al. (2000) spiked soils with pyrene and benzo [a] pyrene and determined desorption in compound free water, water with DOM at a concentration of 200 mg C L<sup>-1</sup>, and water with CaCl<sub>2</sub> added to achieve the same ionic strength as in the DOM solutions. The DOM was derived from composts and organic wastes. Much higher desorption in the DOM solutions than the others was measured, suggesting a binding of the chemicals to DOM.

**Abbreviations:** DOM, dissolved organic matter; NoSS, without sewage sludge application; OM, organic matter; SS, with sewage sludge application.

The formation of a complex between napropamide and DOM was found to cause a small fraction of the napropamide to move as if it had no adsorption through the soil columns in the laboratory (Nelson et al., 1998, 2000a, 2000b; Williams et al., 2000). Thus the potential for an interaction between a pesticide and DOM, which could affect the transport of the pesticide through soil, is well established in the literature.

Soil OM may serve conflicting roles in mitigating pesticide transport through soil. The fact that increasing soil OM increases the value of  $K_d$  has been reported in numerous publications and is a well-recognized phenomenon. Conversely, soil OM can be a source of DOM, which can complex the pesticide and increase probability of ground water degradation through DOM, facilitated transport.

Addition of OM to soils is generally thought to improve soil properties. Indeed, Karlen et al. (1997) listed OM as one of the selected indicators of soil quality. The processes identified as being affected by OM include nutrient cycling, pesticide, and water retention and improved soil structure. Therefore, addition of solid OM to soils is done to improve soil properties. However, the addition of OM would have a negative consequence if it contributed to DOM facilitated transport of pesticides.

A laboratory procedure that could be used to treat a soil for properties conducive to DOM enhanced transport of pesticides would be valuable. We pursued two objectives. First, develop a laboratory procedure that could be used to determine the susceptibility of a soil to DOM facilitated transport of pesticides; and second, test the validity of the procedure. This paper reports the rationale, which led to a hypothesis for a proposed procedure and then results of a laboratory study that tested the hypothesis. The following rationale was used in developing the hypothesis. In the field, pesticides are typically sprayed on the soil surface, which usually dries before rain or irrigation transports the chemicals into the profile. After water is applied some of the pesticide is dissolved or desorbed into solution. As the solution moves down the profile the pesticide can be adsorbed from this solution by soil surfaces. However, if a stable pesticide-DOM complex that is not adsorbed by the soil is formed, then this portion of the pesticide will be transported rapidly with water through the soil.

We propose a two-step procedure. First, known concentrations of pesticide are applied to soil and allowed to dry. Later the soil is brought to equilibrium with napropamide free water and the adsorption coefficient is calculated based on the known amount of pesticide added and the resultant pesticide in solution. This coefficient will be referred to as  $K_1$ . The second step is to take the extract produced during the first step and mix it with pesticide-free soil. After equilibration the concentration of pesticide remaining in solution is measured and used to calculate an adsorption coefficient that will be identified as  $K_2$ . If a nonadsorbing pesticide-DOM complex was formed during the dissolution process, then the value of  $K_2$  would be less than  $K_1$ .

We hypothesize that the ratio of  $K_1$  to  $K_2$  is an indicator of the potential for facilitated transport of a pesti-

cide by DOM. The larger the ratio the greater the potential for transport.

## MATERIALS AND METHODS

Napropamide was selected as a model compound. It represents a group of polar nonionic herbicides and has an aqueous solubility of  $74 \text{ mg L}^{-1}$ ; vapor pressure of  $1.7 \times 10^{-7} \text{ mm Hg}$ ; KOC equal to  $700 \text{ L kg}^{-1}$ ; and degradation half-life of 70 d (Wauchope et al., 1992). It is a selective herbicide used for controlling several grass and broadleaf weeds in various crops. Carbon-14-labeled napropamide was supplied by Stauffer Chemical (now Zeneca Agrochemicals) with a radiochemical ( $^{14}\text{C}$ -a-naphoxy) purity of 99%. Two dimensional thin layer chromatography was used to confirm that 90% of the impurities was the  $\beta$ -congener of napropamide, meaning that  $<0.04\%$  of the  $^{14}\text{C}$  activity could be attributed to water soluble compounds (personal communication, 1989, Stauffer Chemical, Richmond, CA). In preliminary studies gas chromatography was used to confirm in preliminary studies that  $^{14}\text{C}$  activity in experimental samples was napropamide.

Three soils were selected for investigation. One soil was an Airport silt loam (fine-silty, mixed, active, mesic Aquic Natrixeroll) taken from adjacent fields to which sewage sludge had been applied (SS) and without sewage sludge application (NoSS). The sludge amended soil received  $137 \text{ Mg}$  (dry weight) sludge  $\text{ha}^{-1} \text{ yr}^{-1}$  for three consecutive years. Soil OM in SS was well humified as the soil was collected 2 yr following the last sludge application. Another soil was Milpitas fine sandy loam (fine, smectitic, thermic Mollic Palexeralfs) taken from adjacent citrus groves where different depths of wood mulch had been applied for seven continuous years. The first site was continuously maintained with 10 to 15 cm of mulch (M, 10–15) and the second site was continuously maintained with greater than 30 cm of mulch (M, 30). The third soil was a Camarillo sandy loam (fine-loamy, mixed superactive, calcareous, thermic Aquic Xerofluvents) that had been treated with continuous eucalyptus bark mulch for 5 yr. The first site had been maintained with 15 to 20 cm of mulch (E, 15–20), the second had been maintained with greater than 30 cm of mulch (E, 30), and the third site was untreated (E, 0). For the soils that had received surface mulch treatment, the mulch was scraped off of the surface and the approximately 15-cm soil layer immediately below the mulch was collected. The soils were air dried and sieved through a 2-mm screen. The soil OM was measured using the Walkley-Black procedure (Nelson and Sommers, 1982).

The adsorption isotherms were obtained using the following procedures. Carbon-14-labeled and non-labeled napropamide with a labeled to non-labeled ratio of 1:9 (w/w) were added to pesticide grade acetone (A) or dionized water (W) to create solutions with concentrations of 5, 10, 25, and  $50 \text{ mg L}^{-1}$ . Acetone was used as a solvent to facilitate rapid evaporation and facilitate napropamide dissolution similar to emulsifiers found in commercial formulations. Water was used, as a control, to determine if the acetone used as a carrier was responsible for observed responses (Nelson et al., 2000b).

Eight milliliters of the napropamide solutions were applied to 80 g soil in aluminum pans resulting in herbicide concentrations of 0.5, 1.0, 2.5, and  $5.0 \text{ mg kg}^{-1}$  soil. The solution was applied to the soil in a dropwise manner and the soil stirred for uniform herbicide distribution. The soils were allowed to dry in the dark at  $23^\circ\text{C}$  for 72 h to allow evaporation of the carrier solvent. After drying, 80 g of treated soil were placed inside 250-mL Teflon centrifuge containers and filled with 160 mL of dionized water to which NaCl and  $\text{CaCl}_2$  had been added to create an electrical conductivity (EC) of  $1 \text{ dS m}^{-1}$ ,

and a sodium adsorption ratio (SAR) of 2. Unless otherwise stated, this water was used in all studies reported here. The containers were shaken for 2 h, centrifuged for 30 min at  $1600 \times g$  and the supernatant extracted. Previous studies using this technique showed that 2 h were sufficient for equilibrium (Nelson et al., 1998, 2000b). Carbon-14-labeled napropamide concentration in solution was measured by liquid scintillation. These data were used to calculate the concentration of adsorbed napropamide at equilibrium with a solution concentration. A plot of the adsorbed versus the solution concentrations resulted in a linear relationship and the slope of the curve was used to calculate  $K_d$ . The adsorption coefficients obtained in this manner will be designated as AK1, when the napropamide was added in acetone, and WK1 when napropamide was added in water. This procedure was replicated three times.

A portion of the extracted solution was used to measure dissolved organic C. Organic C was measured in a 20- $\mu$ L sample by ultraviolet promoted persulfate oxidation followed by infrared detection using a Dohrmann DC-80 organic C analyzer (Xertex, Santa Clara CA). Inorganic C was removed before analyses using acidification followed by external sparging with  $N_2$  gas and the C contributed by napropamide was subtracted. The term DOM is used in this report since it is the whole organic molecule that participates in the interaction and not just the C.

Adsorption from the extracted solutions was determined next. A total of 20 mL of the extract solutions were placed in 50-mL Teflon centrifuge tubes to which 10 g of untreated soil was added. The centrifuge tubes were shaken for 2 h, centrifuged for 10 min at  $4000 \times g$  and the supernatant extracted. The  $^{14}C$ -labeled napropamide concentration was analyzed by liquid scintillation and the adsorption coefficients calculated as described above. These adsorption coefficients will be referred to as AK2 and WK2.

The napropamide transport studies were conducted in columns constructed of 2.86 cm (id) acrylic plastic tubing with a length of 45 cm. A Teflon disk perforated with small holes was fastened to the bottom of the column to retain the soil while allowing drainage. Untreated air-dried soil was continuously poured into the columns and then packed to a height of 10 cm by lightly tapping the sides of the column walls. A 5-cm layer of napropamide treated soil was placed on the untreated soil. The resultant bulk density of the soil was  $1.2 \text{ Mg m}^{-3}$ . Procedures as described above for the adsorption studies were followed to treat the soil. However, only napropamide dissolved in acetone to create a concentration of  $5 \text{ mg kg}^{-1}$  soil was used in the column studies.

Water was applied to the dry soil columns through a Mariott bottle apparatus to control the head. The head was maintained at a level to cause a flow rate of  $0.30 (\pm 0.05) \text{ cm}^3 \text{ min}^{-1}$ . The leachate was collected after every 5 mL and stored in glass vials. Water was allowed to flow until approximately 100 mL had passed through each column. Soil leachates were immediately analyzed for  $^{14}C$  activity, DOM content, pH, and EC. Each treatment was replicated three times.

The soil columns were sectioned after drainage was complete. The top 5-cm treated layer was removed and the lower part of the column sectioned into 1-cm layers. Each sample was allowed to dry and then mixed for uniform distribution. A 0.5-g soil sample was mixed with 20 mL of pesticide grade methanol and shaken for 12 h. The sample was then centrifuged for 10 min at  $4000 \times g$  and 1 mL of supernatant was mixed with 19 mL scintillation cocktail and the  $^{14}C$  activity was measured in a scintillation counter. The fraction of the applied napropamide retained in each layer was calculated. The recovery in the soil and the effluent ranged from 92 to 98%.

## RESULTS

The OM content, DOM, and various measured adsorption coefficients are reported in Table 1 for the soil samples. Placing mulch on the soil surface increased the OM and DOM of the underlying soil. Increasing the depth of mulch tended to increase the OM and DOM of the underlying material. Application of sewage sludge to the soil slightly increased the OM and DOM content as compared with the soil that did not receive any sludge. In every case, the value of K1 was greater than K2. This can be explained in three ways. First it may be due to different initial concentrations between the K1 and K2 isotherms and the nonlinearity of the isotherm over large concentration ranges. Second K1 being greater than K2 could be due to reduced sorption. This explanation would result in increased napropamide mobility in the transport studies. Finally a combination of both of the above explanations may be responsible. The present study was not meant to answer the first postulate, however, the results of the column study can determine if the second explanation is responsible for any of the observed results.

The K1/K2 ratio is plotted as a function of percentage of OM in Fig. 1. A positive relationship between OM content of the soil and the K1/K2 ratio occurred when all of the soils are pooled. The resulting linear relationship is quite strong considering that only total OM is being evaluated and not any other component of the soil system such as type of OM or mineral composition of the soils. Application of the napropamide in acetone generally resulted in a higher K1/K2 ratio because of a lower K2 value than when napropamide was added with water. This might be explained because the acetone can provide access to more hydrophobic regions of the OM than water and therefore promote the formation of a DOM-napropamide complex.

We postulated that the K1/K2 ratio would be an indicator of the magnitude of napropamide that would be rapidly transported through the soil as a result of a napropamide-DOM complex. The concentration of napropamide in the leachate was highest in the first collected sample and decreased with increasing leachate volume, which would be expected for a nonadsorbing chemical. The first 30 mL of leachate was collected and represents the first pore volume to pass through the dry untreated soil. Traditional values for  $K_d$  were determined for each soil and ranged from 4.9 to 12.3 resulting in a range of  $R$  values of 14 to 34. This means that all of the napropamide transported through the columns in the first 30 mL was a result of processes that are not properly characterized by  $K_d$  and  $R$ . This also represents evidence that the greater K1 values (compared with K2) can at least be partly attributed to a real reduction in napropamide sorption. If the differences in sorption were due solely to concentration differences in the isotherms the untreated soil beneath the treated layer would have retarded the movement of napropamide, however, napropamide was found in the initial leachate. Others have shown this increased mobility to be a result of reduced sorption (Nelson et al., 1998, 2000a, 2000b; Williams et al., 2000). After 30 mL of leachate the concentration of napropamide had fallen to  $<10 \text{ ng L}^{-1}$  in all of the columns.

**Table 1.** The organic matter (OM), dissolved organic matter (DOM), fraction of napropamide retained in the top treated layer (F), and various adsorption coefficients for the various soils.

	Camarillo sandy loam‡‡			Milpitas sandy loam§§		Airport silt loam¶¶	
	E, 0	E, 15–20	E, 30	M, 10–15	M, 30	NoSS	SS
% OM†	1.4	3.1	3.8	4.2	5.4	2.4	2.7
DOM, mgC L <sup>-1</sup>	43.7	101.9	100.7	86.3	146.9	65.9	73.48
AK1‡§	5.0	10.2	10.6	14.1	25.4	8.3	12.1
A K2¶	4.7	4.9	6.9	6.6	7.2	4.2	5.8
W# K1	5.3	9.7	11.1	13.6	19.7	8.1	12.5
W K2	4.9	6.4	7.3	9.2	8.7	6.3	8.9
K <sub>a</sub>	4.9	6.7	9.4	10.3	11.1	8.3	12.3
AK1/AK2	1.07	2.06	1.53	2.14	3.52	1.98	2.08
WK1/WK2	1.08	1.51	1.51	1.47	2.28	1.29	1.40
F††	0.15	0.53	0.46	0.56	0.64	0.44	0.75

† Walkley-Black procedure used (Nelson and Sommers, 1982).

‡ Napropamide applied to soil in acetone and allowed to dry.

§ Solution resulting from equilibrating dry treated soils with napropamide free water.

¶ Solution resulting from equilibrating S1 solution with untreated soil.

# Napropamide applied in water and allowed to dry.

†† Fraction of napropamide retained in top treated layer.

‡‡ E, 0, Camarillo sandy loam without mulch treatment; E, 15–20, Camarillo sandy loam with continuous 15- to 20-cm layer of eucalyptus mulch; E, 30, Camarillo sandy loam with continuous &gt;30-cm layer of eucalyptus mulch.

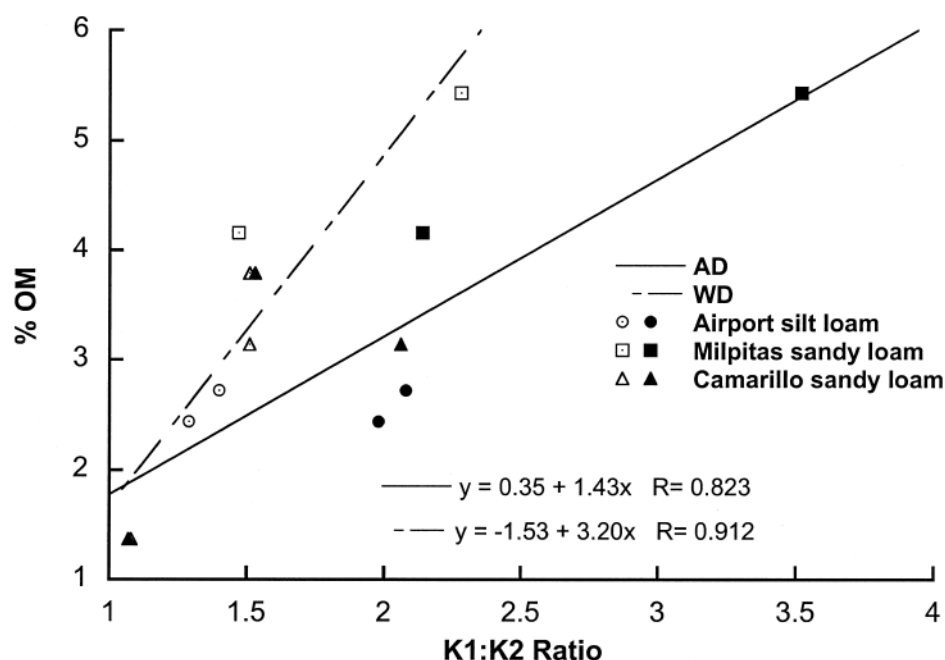
§§ M, 10–15, Milpitas fine sandy loam with continuous 10- to 15-cm layer of mulch; M, 30, Milpitas fine sandy loam with continuous &gt;30-cm layer of mulch.

¶¶ NoSS, Airport sandy loam without sewage sludge application; SS, Airport sandy loam with sewage sludge application.

The relationship between K1/K2 ratio and the fraction of the applied napropamide that appeared in the first 30 mL volume of leachate is presented in Fig. 2 (open symbols). The amount of napropamide leached tends to increase as the K1/K2 ratio increases. This is particularly true in comparing results for individual soils. Thus the measurement of the K1/K2 ratio can be used as an indicator of rapid transport of napropamide through soil but cannot be used accurately to quantify the amount when comparing different soils. Note however that for all soils the maximum napropamide leached is <4% of the total applied.

In Fig. 2 the fraction of the napropamide leached in the first 30 mL is also plotted as a function of percentage

of OM (closed symbols). For a given soil, increasing the OM increased the amount of napropamide rapidly transported through the column. However, the amount of rapidly transported napropamide is not as sensitive to the percentage of OM, and thus OM content is not as good an indicator of rapid transport as the K1/K2 ratio. When linear regression is applied to the K1/K2 ratio and the percentage of OM as a function of the fraction of napropamide leached in the first 30 mL the coefficient of determination is 0.45 (significance at the 95% level being any  $r > 0.41$ ) for the K1/K2 ratio and 0.15 for the percentage of OM. Again this indicates that the K1/K2 ratio is a better predictor of facilitated transport than the percentage of OM. For example, applying a mulch



**Fig. 1.** Linear relationship between the ratio of the K1/K2 solution  $K_a$ 's for each treatment and soil organic matter. Closed symbols are for treatments where napropamide was applied in acetone and allowed to dry. Open symbols are for treatments where napropamide was applied in water and allowed to dry. Regression lines are computed based on pooling all treatments where napropamide was applied in acetone (solid line) and all treatments where napropamide was applied in water (broken line).

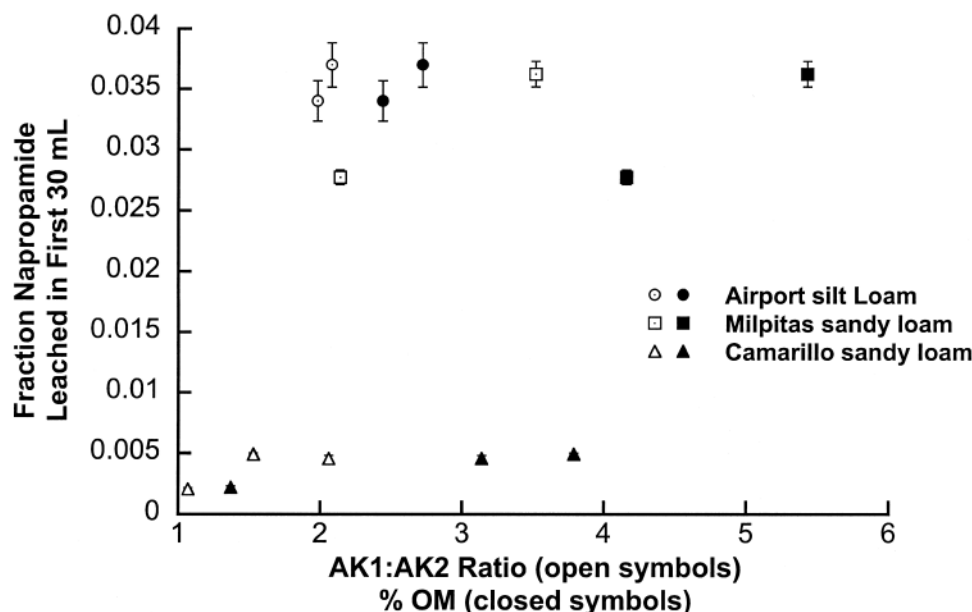


Fig. 2. Relationship between soil organic matter content (closed symbols) and the ratio of the K1/K2 solution  $K_d$ 's (open symbols) and for each treatment and fraction of applied napropamide leached in the first 30 mL of effluent. Napropamide was applied to soil allowed to dry and a 5-cm treated soil layer was placed over a 10-cm untreated layer and irrigated with a constant head. Error bars are  $\pm 1$  standard error of the mean. In some cases error bars are smaller than the symbols.

over the Camarillo soil created an OM content of the soil that is higher than measured in the Airport soil. However, more napropamide was transported through the Airport soil than the Camarillo soil even though it had lower OM content. Measurement of the K1/K2 ratio partially corrected for the differences in soil OM. The K1/K2 ratio will also take into account the sorption characteristics contributed by other soil characteristics such as clay content that are not measured in OM content.

The fraction of napropamide retained in the treated top 5 cm increased as the percentage of OM increased (Fig. 3) and as the value of K1 increased (Fig. 4). These results are completely consistent with well-established

principles that increasing OM increases K1 and increasing K1 increases the retardation coefficient. The OM associated with sewage sludge applied to the Airport soil appeared to be particularly effective in increasing the adsorption and retardation of the movement of napropamide.

The distribution of the napropamide in the untreated underlying section of the column after leaching and drainage is presented in Fig. 5. As expected, the depth of movement of napropamide increases as the fraction retained in the upper layer decreases associated with a lower retardation coefficient. Significantly, the concentration of napropamide in the bottom layers were below

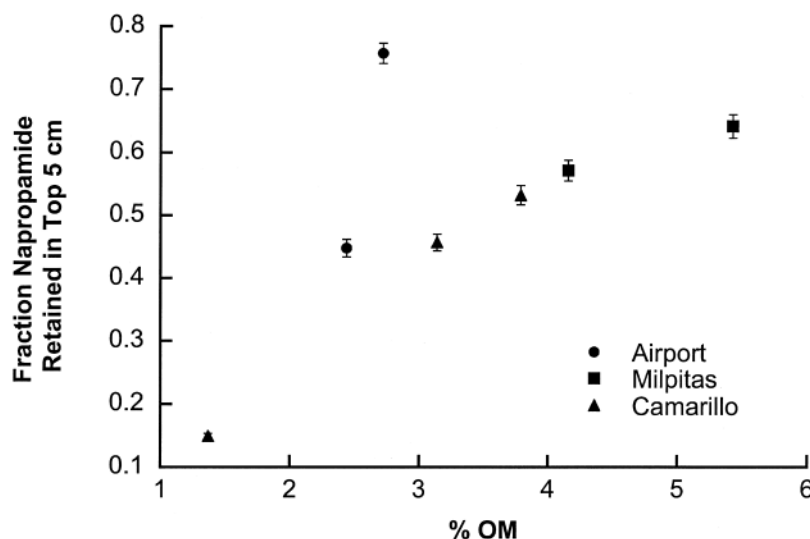


Fig. 3. Relationship between the soil organic matter content for each soil and the fraction of applied napropamide retained in the treated layer following 100 mL of cumulative leachate and draining. Napropamide was applied to soil allowed to dry and a 5-cm treated soil layer was placed over a 10-cm untreated layer and irrigated with a constant head. Error bars are  $\pm 1$  standard error of the mean. In some cases error bars are smaller than the symbols.

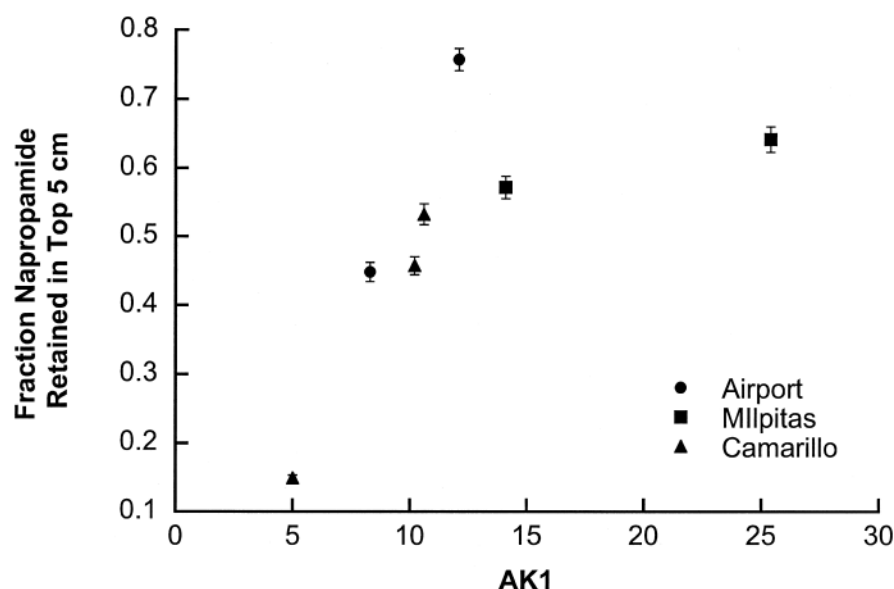


Fig. 4. Relationship between the K1 distribution coefficient for each soil and the fraction of applied napropamide retained in the treated layer following 100 mL of cumulative leachate and draining. Napropamide was applied to soil allowed to dry and a 5-cm treated soil layer was placed over a 10-cm untreated layer and irrigated with a constant head. Error bars are  $\pm 1$  standard error of the mean. In some cases error bars are smaller than the symbols.

detection limits for all soils. Clearly the napropamide, which was captured in the effluent moved through the profile with essentially no adsorption.

One purpose of the research was to investigate the transport of napropamide through soils that had been collected in the field receiving various solid OM applications. Placing mulch on the soil surface increased the OM content of the soil beneath the mulched layer. The increase in OM increased the adsorption coefficient of napropamide to the soil. This had the effect of increasing the retardation coefficient and maintaining the bulk of the napropamide mass in the shallower depths of the soil (Fig. 3 and Fig. 5). However, the increase in OM also increased the rapid transport of a small fraction of napropamide through the soil (Fig. 2). Thus OM serves conflicting roles in mitigating the potential for ground water contamination from pesticides. Organic matter retards the transport of the major mass of applied pesticide but on the other hand increases the probability for the very rapid transport of a small fraction of the applied napropamide. Therefore, a trade-off exists which must probably be evaluated on a site-specific basis. If the water table is deep and the overlying soil material is low in OM, it is possible that the complexed napropamide would be adsorbed thus attenuating its movement to the aquifer. If the water table is high, resulting in drainage to surface water supplies, the rapid facilitated transport might contribute to degradation of surface waters.

The major goal of this research was to test the hypothesis that the K1/K2 ratio could be used as an indicator of the potential for facilitated transport of pesticide by DOM. The results presented in Fig. 2 revealed that the ratio is an indicator, but that it has limited quantitative predictive ability when comparing different soils. Because only a small percentage of the applied napropamide was rapidly transported, the quantitative estimate is not as important as the qualitative estimate for predicting the

potential for facilitated transport. In this regard, measuring the K1/K2 ratio has utility, particularly in screening sites for high risk as sources of pesticide contamination of water.

#### ACKNOWLEDGMENTS

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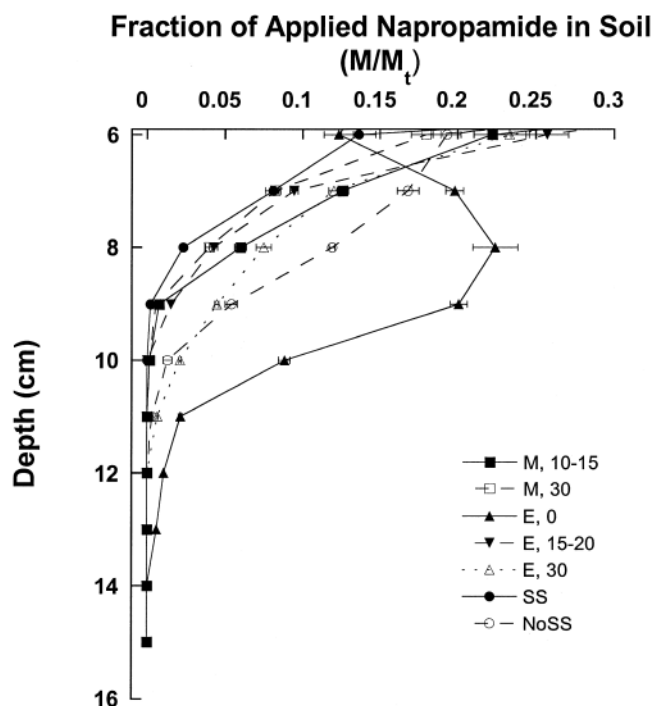


Fig. 5. Final distribution of napropamide in soil columns following irrigation treatments. Distribution represents the readsorption of napropamide desorbed from the treated layer onto the untreated soil below. Error bars are  $\pm 1$  standard error of the mean. In some cases error bars are smaller than the symbols.

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